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# ENERGY EFFICIENCY IN HISTORIC BUILDINGS

BY

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**Abstract.** Refurbishment of historic buildings is a unique condition in many European Countries. Due to the need of developing a harmonized approach focusing on historic buildings rehabilitation, in 2014 AiCARR published a specific Guidelines. On this base, a further effort has been made developing an updated and revised guide at European level on the behalf of REHVA and with the inclusion of case studies from several European countries. In this work, the methodology to carry out energy audit of historic buildings is described, as implemented in the Guidelines, which focus on the needs and peculiarities of the cultural heritage that designers have to face with. The proposed methodology also provides to the institutions, responsible for protecting the building, objective criteria in deciding what energy saving opportunity is complying or not with conservation purposes.

**Keywords:** Historic buildings, energy efficiency, energy audit.

## 1. Introduction

In many Countries, and especially in Italy, where historic buildings are a consistent part of the building stock, the redevelopment of historic buildings is a priority and a cultural and technical challenge. It is cultural, because is operated

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on buildings that represent a historical document for their architectural and technological features, and it is technical because very often are required novel and advanced techniques compliant with the respect of the artefact and the constraints imposed by protection authorities.

One of the critical aspects of the energy improvement is just related to the protection constraints, which often do not allows any intervention on the building and the system, when existing and in operation. Even worst the installation a new system from scratch, which could be considered an invasive and therefore not feasible procedure.

Another critical issue is the different responsibilities among designers and other players involved in energy conservation, restoration, conservation and preservation of historic buildings, which often leads to misunderstandings related also to different cultural background and linguistic codes. Finally, very often the techniques and technologies used for upgrading the energy efficiency, even if respecting the building, may negatively affect the cultural landscape.

Thus, due to the need of developing a harmonized approach focusing on historic buildings rehabilitation, in 2014 AiCARR published a specific Guidelines entitled “Energy efficiency in historic buildings” (AA.VV., 2014) intended for both design engineers and Public bodies in charge of their conservation to support energy retrofit actions in historic buildings. The aim was to create a common language for the different disciplines involved.

In 2017 the European Standard EN 16883 "Conservation of cultural heritage - Guidelines for improving the energy performance of historic buildings" (CEN, 2017) has been published, which prescribes the criteria to be used when you want to redevelop a historic building from the energy point of view.

Following the approach of the CEN standard, the existing AiCARR guide on "Energy Efficiency in historic building" (AA.VV., 2014), was completely revised, updated and extended at European level on the behalf of REHVA. In the following, the employed methodology to carry out energy audit of historic buildings, as implemented in the new REHAV Guide (REHVA, 2017), is described underlining systematically the peculiarities of such specific application.

## 2. EN 16883 Standard

The European Standard EN 16883 contains Guidelines for energy refurbishment of historic buildings. The document, written by experts in conservation and energy efficiency in historical buildings of all types and ages, defines an historic building as single manifestation of immovable tangible cultural heritage in the form of an existing building that does not necessarily have to be a heritage-designated building.

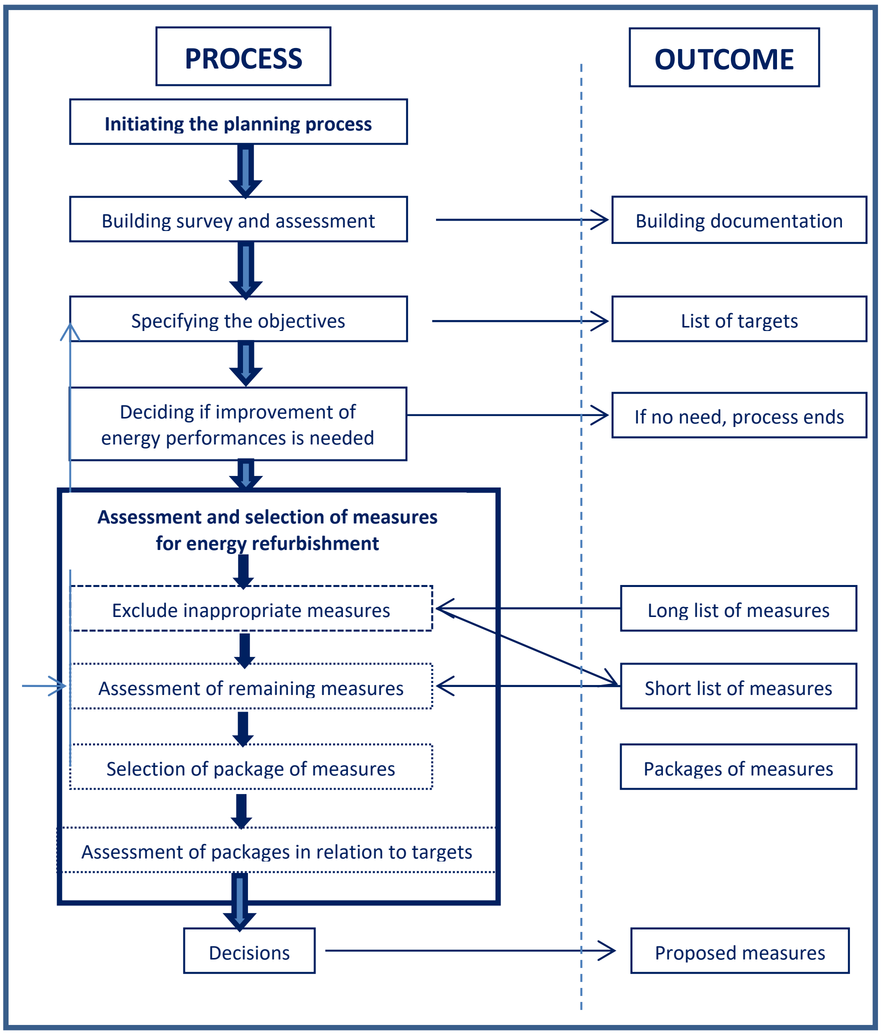


Fig. 1 – Energy Audit procedure for historic buildings (CEN, 2017).

This European Standard thus provides guidelines for sustainably improving the energy performance of historic buildings, e.g. historically, architecturally or culturally valuable buildings, while respecting their heritage significance. The scope of the Standard is then to underline the peculiarities of historic buildings and the need of a careful and interdisciplinary analysis aiming to know how to optimize energy and conservation aspects. Each historic building has to be considered as a particular case. To achieve this goal, the Standard presents a systematic approach, or procedure, which could not presuppose a need for energy improvements in all historic buildings. This normative working procedure for selecting measures to improve energy performance is based on an investigation, analysis and documentation of the building that includes its heritage significance, assessing the impact of those measures in relation to preserving the character-defining elements of the building. In Figure 1 the iterative process for determining the best intervention is shown, which constitutes what can be called as the Energy Audit of Historic Buildings.

Such approach has been followed in producing the REHVA guide, detailing each section of the procedure as much as possible without losing generality and applicability. Moreover, some side information has been provided in the appendixes to support practical application of the given procedure.

## 3. Historic buildings rehabilitation process

Historic buildings are the living legacy of centuries of evolution and innovation. As Climate Change mitigation and energy security issues demand for Energy Efficiency, many ancient buildings are either excluded from the common effort or pushed towards “deep renovation” goals they were never designed to provide or endure. Moreover, very often, cultural heritage is scattered around the country and, in some cases, it is composed of a series of artefacts and buildings, which, while they are not of any particular relevance individually, together they constitute a whole that defines the specificity and historical memory of a particular place. One of the features of this whole is its considerable fragility, making it extremely vulnerable to even small changes in the external morphologies and colours of the buildings. On the other hand, the improvement of energy performance in historic buildings is generally obtained through architectural changes, which more than often generate important effects on the characteristics that define the testimonial value. In addition, the fragility of historic buildings is both of an aesthetic-formal and structural nature, in that the implementation of technological systems, which have not been designed properly, can have repercussions on the statics of the building. A recurring case of this event is the construction of rooms or shafts to house the technological systems that are not compatible with the statics of the building subject to the work. In addition to this critical issue is often the absence of documentation on the work undertaken, thus making it extremely difficult for any work to be carried out to mitigate the potential damage or damage that has been caused. From this observation stems the need to raise the designer’s awareness in carrying out his activities through a path of knowledge of the artefact to gain a deeper understanding of the nature of the building and the role it plays within the landscape.

Energy redevelopment must avoid adaptation and must ensure the conservation of the features that define the testimonial character of the historic building. Its energy refurbishment also has to comply with any constraints imposed by national or local authorities in charge of protection and preservation of cultural heritage.

This path of knowledge must be based on a survey of geometric, constructive, material and stratigraphic characteristics of the historic building and its service systems and the requirements linked to the needs of the current use of the building, to ensure an overall awareness among all the designers involved in a deeply controlled modification of the property. The survey should not be limited to the building but have to take also into consideration the neighbourhood for evaluating any possible impact on it or any possible synergic action, which could lead to cost reduction (scale effect and repeatability effect).

Even in the case of interventions aimed at improving energy efficiency, the survey cannot ignore the architectural, artistic and structural aspects of the building, so that an accurate critical analysis can be made in relation to the parts that can be modified without damaging the artefact and those in which the invasiveness of the work must be minimized. Therefore, it is not only of a survey relating to the service systems of a building, but a complete geometric, architectural and degradation survey, integrated with a complete historical and documentary analysis, with the addition of in-depth studies relating to its original bioclimatic passive characteristics and, eventually, its original service systems.

Of course, in an environment with a strong interdisciplinary approach this work must involve all the specific skills and must envisage the coordination and supervision of the Director of the restoration and the local authority representative appointed to protection and preservation of cultural heritage. Therefore, the assembly of a qualified team is mandatory for a successful work. In fact, only informed, technically able and financially capable decision makers - a very small number- can act consciously towards emissions reduction and concurrent cultural heritage conservation, and from those only a few can access possible available funding. Thus, this team ideally should consist of a preservation architect, mechanical engineer, electrical engineer, structural engineer, and preservation consultants, each knowledgeable in codes and local requirements. If a special use (church, museum, art studio) or a collection is involved, a specialist familiar with the mechanical requirements of that building type or collection should also be hired. Team members should be familiar with the needs of historic buildings and be able to balance complex factors: the preservation of the historic architecture (aesthetics and conservation), requirements imposed by mechanical systems (quantified heating and cooling loads), building codes (health and safety), tenant requirements (quality of comfort, ease of operation), access (maintenance and future replacement), and the overall cost to the owner.

Thus, compared to a standard energy audit procedure, the historic building energy audit starts from the historical knowledge of the building itself, of the urban historical context around it and of the surrounding climate, taking into account the historic and artistic value of the artefact and the landscape when looking for the most appropriate energy savings strategies. This procedure can then be summarized in the following macro-phases: anamnesis, diagnosis, and prognosis.

## 4. Building anamnesis

In this context, the anamnesis, i.e. a recalling to mind previous condition of something, is focused on reading the historic sources and iconography of the building to individualize the different historic stages of the building construction, in chronological order. In fact, historic building assessment cannot disregard the historical analysis of the functional evolution of the building and its articulations, with the purpose of gaining knowledge on modifications implemented to the artefact and the final use of each room over the years. In historic buildings, constructive strategies, based on centuries of traditional knowledge trial and error optimization practices, have been properly applied and used, resulting in some expected behaviour. Load bearing walls, made of stones or bricks, together with wooden made floors have been widely used successfully before casted concrete introduction. In time, these original designs become blurred or outdated by newly imposed uses and successive 'contemporization' actions to match their users' evolving needs and expectations introduced structural, architectural and functional modification. Some new floors have been added using different technique overloading the original structure. Some windows have been closed and some new created in different positions modifying the building statics equilibrium. All these modification have been done with a true belief on the advantage of the improvements, without a complete consciousness of its full repercussions, favouring instead pathologies, like material degradation due to moisture formation, thermal bridges, cracks due to different thermal expansion between new and old materials, and so on. In most of the cases, all these "improvements" are today important issues to solve.

The result of this analysis makes available information, which is useful to understand the causes of deterioration of materials and structures, to plan possible future uses that are compatible with the characteristics of the building and to improve energy performance. An attentive observation on the imposed changes and their results is an opportunity to evaluate those to be preserved or not, and to self-question the unanticipated impacts of our own planning.

Acknowledging that adaptations are often necessary, the awareness of previous uses and limitations allows for palliative solutions: for instance, basements can be adapted to host highly ventilated functions like garages, technical rooms and open-door services that reduce the rising humidity issues, and inherent air quality risks.

Thus, understanding historic buildings usage within their timeline and context—from original design to intended future uses—should precede every retrofit intervention.

## 5. Building diagnosis

The foreseen procedure then involves some actions aimed to formulate a judgment on the building condition in the actual status and the functionality of both its fabrics and its plants and service systems. The analyses of both envelope and service systems have to consider, other than usually done in an energy audit, with special care in evaluating the conservation status and the reusability of each building component. Furthermore, the compatibility of possible retrofit interventions for rehabilitating the building at its historical destination or to new functionalities has to be investigated and compliances with Cultural Heritage preservation laws have to be verified, also regarding the landscape preservation. This part of the procedure is here called "building diagnosis" and consists of different phases that regard the envelope and services systems analysis, the energy modelling and evaluation of energy performance of the historic building. After that, a list of possible usual interventions has to be analysed in the view of their compatibility with Cultural Heritage conservation, not only for the building but also for the surrounding landscape, to improve the energy performance: this part is her called "building prognosis".

Figure 2 shows the flow chart of the building diagnosis and prognosis procedure for energy improvement of historic buildings adapted and expanded from (AA.VV. 2014), regarding how to improve energy efficiency while retaining the building historic value.

Before to be able to analyse any part of the building, the first step is of course the execution of a building survey during which any sign of degradation is examined. This action can be considered part of the building diagnosis as its preliminary stage or a separated preceding phase, as well. In any case, it consists of several stages that can be identified as geometrical survey, architectural survey, structural survey, element survey and material survey. Gathered this knowledge, the envelope and service systems analysis can start finalized to the energy modelling and assessment.

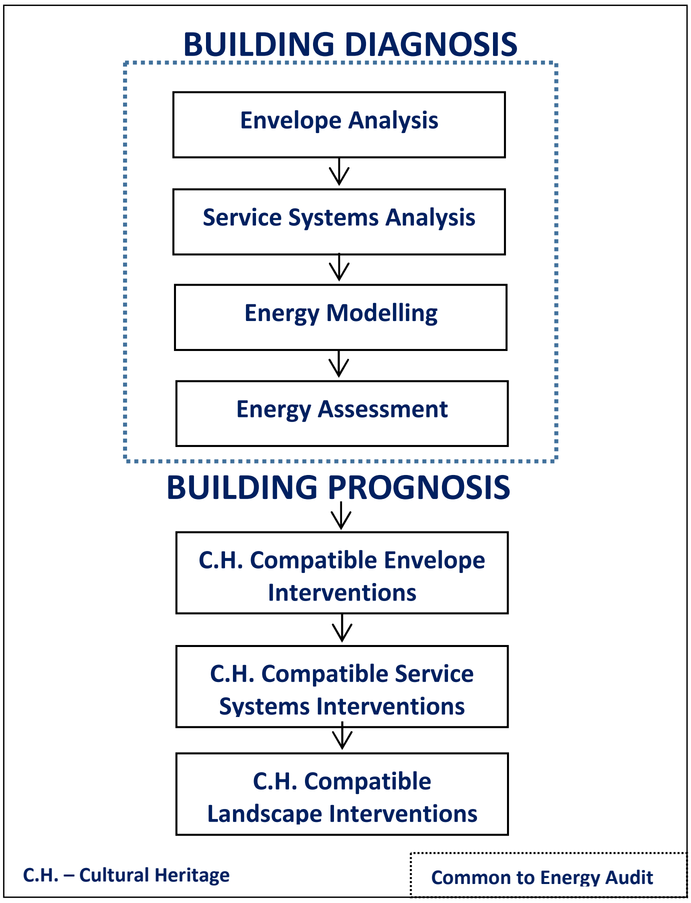


Fig. 2 – Flow chart of building diagnosis ad prognosis. Adapted from (AA.VV., 2014).

### 6. Building prognosis

After that building diagnosis has been formulated, applicable solutions have to be identified among all potential options to quantify the chances of recovery from the actual degraded building status. First of all, significant architectural spaces, finishes and features should be identified and evaluated from the beginning to ensure their preservation. This includes, other than relevant architectural elements as painted cupolas, transoms, or porches, significant existing mechanical systems or components such as artistic hot water radiators or their decorative grilles, external piping and all other valuable elements. The identification of no significant reusable spaces is then a fundamental step because they can be the right places where new mechanical equipment can be placed without altering the building fashion. These spaces might include attics, basements, penthouses, mezzanines, false ceiling or floor cavities, vertical chases, stair towers, closets, or exterior below-grade vaults. At this stage it is important to meet owners or their representatives together with local officials, to clearly define the level on intervention according to their needs and legal constraints, and thus analyse only possible energy improvement that comply with such requirements. Legal requirements have to be checked, verifying, for instance, how the historic character of the building can be maintained while respecting energy, fire, and safety codes and standards in place. For example, existing ductwork could be reused as they are or, instead, to comply with new standards and laws, they must be modified with the use of dampers. If an obligation of stair case ventilation exists, that can affect the exterior appearance of the building. Many of the health, energy, and safety code requirements set up constrains to the designers and reduce the energy saving opportunities relate to the building climate control. Thus, it is importance to know what they are during this phase.

A matrix or feasibility studies then should be developed to balance the benefits and drawbacks of various possible update and improvements to existing systems as substitution with new compatible systems. Factors to consider include heating and/or cooling requirements, fuel type, distribution system, control devices, generating equipment and accessories such as filtration, and humidification, if any. Restoration and reuse of existing components have to be evaluating in comparison with new possible systems, in terms of rehabilitation and installation costs, projected fuel costs, exploitation of on-site renewable energy sources, long-term maintenance, and life-cycle. The benefits of added ventilation should not be overlooked. Trade-offs between one large central system and multiple smaller systems should be evaluated as different system typologies like forced air ducted system compared to a two-pipe fan coil system, or a combined water and air system. Space availability for equipment and distribution system has to be assessed as the fire risk levels of various fuels that may be used. Understanding the advantages and disadvantages of the various types of mechanical systems available and evaluating each of these systems in light of the preservation objectives established during the design phase of planning is the master goal of the prognosis process

The historic building prognosis cannot avoid a landscape integration analysis. Any energy efficiency improvement, in fact, may have an impact on the landscape due, for example, to interventions that, although not directly interfering with the building historic characters, can modify its surroundings through outside plant engineering installations not synergistic with the landscape as it is. This is a subject on which two different cultures clash: that of the average designer, who generally pays little attention to the landscape aspects, and that of one who preserves the landscape and tends to avoid any type of work from being carried out, which may be considered invasive. The result is that the Cultural Heritage Conservation Body based on generic assessments instead of on objective criteria rejects often projects, which instead can significantly improve the building energy performance. In fact, it is certainly not possible to authorise or reject a project proposal only based on an assessment sheet, especially when the proposal regards conservation of protected property. To overcome these obstacles, it is important to create a common table where different needs can be discussed to reach a solution that satisfies everyone. It has been reiterated several times how impossible it is to set rules that apply to all cases and that each case is unique and needs to be evaluated carefully and with vast experience, which may give different results to the previous ones.

Thus, when an energy improvement project could have an impact on the landscape, special attention has to be paid to landscape integration, which must be assessed at different scales of intervention for each typological element based on the following criteria:

- technology, intended as the degree of replacement of the building and system components;
- landscape perception, as morphological, formal and colour perception.

Finally, the tool to be able to analyse correctly all available options together with the conservation and landscape constraints to select the best solution is then the usual energy audit procedure, modified as described in the following.

## 7. Energy Audit procedure

The energy audit is one of the fundamental processes for energy improvement of buildings; thus, it is essential to define clearly its purpose and the execution method. In fact, CEN has published the EN 16247-1 (CEN, 2012) standard, which is the first of a series dedicated to this topic. The energy audit is then defined as a "systematic inspection and analysis of energy use and energy consumption of a site, building, system or organisation with the objective of identifying energy flows and the potential for energy efficiency improvements and reporting them." With reference to the building, a specific standard was released in 2014, EN 16247-2 (CEN, 2014), and the energy audit definition can be specialised as a systematic procedure that aims at:

- defining the energy balance of the buildings as a whole and identifying the possible recovery of dissipated energy;
- evaluating the required conditions of thermal comfort, IAQ and structural safety and identifying appropriate solutions for energy saving;

- evaluating opportunities for energy saving from a technical-economic point of view and optimizing the whole building energy management, such as energy supply contracts and system operating methods, aiming to reducing management costs.

In the case of historic buildings, the energy audit is geared to identify the energy requirements due to the envelope, lighting, heating and cooling of the environment and ventilation, necessary to achieve a use of the spaces and to meet the conservation needs. Obviously, when assessing the measures to be taken to save energy or to replace energy from non-renewable energy sources with that from renewable ones, additional constraints imposed by the need to respect the historic and architectural value of the artefact must be taken into consideration, as underlined in the previous paragraphs.

With specific regard to historic buildings, the improvement of energy performance sometimes could require changes to the architectural organism, which, if not carefully designed based on a correct energy audit, can lead to problems that are affecting the documental and eventually monumental value of the artefact as well as calling into question the structural safety of the building. It follows that the working team, who has to intervene on a historic building - especially if constrained by national conservation acts - is often required to acquire much more the documentation than usual. In fact, it is necessary to them to know about the building, with reference to not only the aspects related to its energy aspect, but also those related to its role in human history and within the urban context and landscape, which it is located in. For these reasons, a team of experts is mandatory to face correctly and effectively such complexity.

In addition, to be borne in mind is that there is a direct relationship between the cost of the energy audit and the amount of data to be collected and analysed and the number of energy-saving opportunities that are identified. It is therefore necessary to make a preliminary distinction between the accepted or acceptable costs of the audit that determine the type of audit that can be performed.

As mentioned in the introduction, the energy audit of a historic building is not a simple process. The first obstacle is the lack of adequate plans and sections, in addition to the lack of knowledge of materials and stratigraphy of the inner and outer walls.

These problems are common to many existing buildings, for which it is not easy to track plans and sections that are significant from an energy point of view, and in which coring is not always possible for the identification of correct thermophysical characteristics of masonry structures. In the case of historic buildings, the task is even more difficult because, unless archive research is carried out, it is not possible to go back to the original plan and any changes that it has undergone over the years or centuries.

From the materials point of view, it is sometimes possible to trace the stratigraphy of the walls in a non-destructive or intrusive way; for example, using endoscopic techniques applied to existing passages or interstices in the masonry. These techniques, however, may be expensive and not always take account of works that have been performed over time to the walls, which are often hidden under more or less valuable plaster and are not always detectable with techniques such as infrared thermography.

What could be of some interest in energy audit applied to historic buildings is the use of a multi-objectives criterion instead of just a cost optimal analysis as usual. A multi-objects analysis applied to historic building can give evidence of different impacts on the cultural heritage aspect of each energy savings opportunity. For energy saving measures on envelop and service systems of historic buildings the multi-objectives analysis objectives can be set as:

- energy savings;
- environmental impact;
- economic evaluation;
- degree of compatibility with the architectural, historical and cultural constraints;
- image (the perception of the building by people as an innovative sustainable example of energy savings and cultural heritage conservation).

Choosing the right indicators and weights, the last two objectives are explicitly underlining the impact of such aspects on the final ranking among all possible solutions.

## 8. Systems compatible design

When analysing the service system improvement or replacement, to be able to achieve the today required comfort level in historic buildings, or the required conditions for their conservation, great attention has to be paid to system partial reuse and integration.

It is clear that a building energy performance improvement cannot exclude interventions on the service systems, unless particular historic, architectural or functional restrictions make them inadvisable or impossible to carry out. HVAC (Heating, Ventilating, Air Conditioning) systems in historic buildings are often obsolete unless in case of ordinary, extraordinary or preventive maintenance interventions. Thus, it must be clear to the working team what kind of service systems are available on the market and might be suitable for the energy improving of an historic building while achieving the thermal comfort and IAQ for human subjects and/or artefacts conservation goals. In the last case, the problem is even more complex because not only the building is a cultural heritage artefact, but also its final use is conservation of other cultural heritage artefacts and their fruition by visitors. These two different goals might conflict each other. If fact, an HVAC system can be designed and operated in very different ways and with different impact on the historic building and/or the conserved artefacts in relation to its technology. Some time it is impossible to find out non-relevant spaces able to host ducts for air systems, while reuse of old piping is possible: thus, despite humidity control is needed, a water based system has to be used imposing other ways to control indoor humidity than primary air systems. But if the artefacts conservation goal is of primarily importance, other more expensive technique have to be employed as room water based dehumidification systems or local absorption devices.

The key actions in designing a compatible low energy system for historic building are then:

- establishment of specific criteria for the new or upgraded mechanical system in the light of cultural heritage preservation and conservation;
- prioritization of the requirements for the new climate control system;
- minimization through smart integration of the impact of the new HVAC on the existing architecture;
- balancing of energy saving and comfort requirements with preservation objectives.

In figure 3 an example is given of such approach in designing an HVAC system for a historic building, specifically of visual impact minimization, non-relevant spaces reuse and reversibility of new elements installation (to be removed in the future without further damage to the building). Heating and cooling capacities for “Camera Picta” (Bonacina ,2014) are provided by 3 heat pump units placed inside the tower of the castle and air ducts are conveyed from the air handling unit to the room air diffusers using the fireplace chimney. An ad hoc air diffuser is just placed inside the “Camera Picta” fireplace and can be easy removed or just masked if needed (fig. 5). The intake and exhaust air ducts are placed inside the fireplace chimney and can be directly extracted from the top (the roof) without any destructive work from the room side.

Fig. 3 − Schematic view of the Northern tower with the main components of the HVAC system.

Fig. 4 − Camera Picta Wedding Chamber in Mantova (Italy) before the HVAC installation.

Fig. 5 − Picture of the air diffusers placed inside the fireplace of Camera Picta without the visual shielding grid.

## 9. Systems maintenance

The overall energy efficiency of a building also depends on the level of maintenance performed, obviously with special regard to the management and maintenance of technical installations.

Maintenance issues should be considered as part of the design process of rehabilitation of historic buildings, included into the design phase, added to the general maintenance plan, and must be consistent with the requirements specified for proper conservation of the entire building over time.

The criteria set out for any kind of intervention on historic buildings apply also to maintenance requirements: to respect as much as possible, the historic nature of the building as it is. In fact, choosing for any new systems component suitable positions according to the conservative requirement is not sufficient: it is also necessary to provide for regular accessibility to those systems components without causing any damage (physical and of its image) to the historic building. Furthermore, care must be taken to control the physical and chemical characteristics as well as the behaviour of new materials over time to prevent the occurrence of events that are incompatible with the proper life of the historic building.

Usually maintenance plans just forget to include the most important system for a historic building: the control system. This subsystem potential malfunctioning is more important in such buildings than others for their sensitivity to any internal (other than external) changes in the environmental parameters as temperature, air humidity, pollutant concentration, etc.. If frescos and other climate sensible artefacts (panel painting, tapestries, portraits, antique furniture, etc.) are in the building, microclimate control should be mandatory for their conservation. Thus, a control system malfunctioning is not only reducing the building energy performance but also increasing the risk of damaging cultural heritage artefacts. Even more, if the building is used as museum, collection, or archive, the climate control system will require constant monitoring and tuning. Backup systems are also needed to prevent damage when the main system is not working. Thus, when dealing with historic buildings, due to their nature and potential use, the maintenance plan should focus more on the conservation aspects and should include verification that appropriate temperature, humidity and pollutants concentration levels are maintained to meet conservation requirements without accelerating the deterioration of the historic building materials, and an emergency plan for both the building and any curatorial collections in case of serious malfunctions or breakdowns has to be ready.

## 10. Application Examples: Le Losserand, Hotel d'Activité - Paris (France)

**Context:** Historic centres
**HVAC system size**: Medium
**Site**: Paris, rue Raymond Losserand, XIV arrondissement
**Designer**: Emmanuel Saadi, Jean-Louis Rey; la Sagi (executive) Company: Campenon Bernard Construction, BS VISION Consultant: BECT
**Owner**: Municipality
**Rehabilitation year**: 2007
**Function and use**: Hotel
**Improvements:** glass-integrated PV system
**Supplier:** Photowatt, Bourgoin-Jallieu, France (Sheuten in Germany)
**Installed power:** 123 kWp
**Total Area**: 7958 m²
**Energy saving:** 80,000 kWh/a.

Example of harmonious integration between innovative technology and architectural restoration, Le Losserand - Hôtel industriel, by producing energy, is in line with the intended use of the historic-industrial artefact.
In fact, it is a conversion project of the sub-power station "Compagnie Parisienne de Distribution d'Electricité" (today, known as EDF - Electricité de

France) for small and medium-sized enterprises, with full-height external openings that integrate 45000 photovoltaic cells in glazing.
The photovoltaic cells, made of polycrystalline silicon, are 15 cm ·15 cm in size and are placed between two sheets of exterior laminated glass with an argon cavity, to increase the thermal resistance of the whole component, and an internal glass.
The arrangement of the cells in the windows, that is, the alternation of the photovoltaic system and plain glass comes from a photograph of the millstone existing in masonry piers that surround the windows. This image is translated into pixels (through pixelisation) and allows the glass pattern to be generated: the façade composition is obtained from the sequence emulation of the colour variability of the stone.
The division is also affected by the exposure of the façade: 60% of the surface on the south side consists of photovoltaic cells inserted in the window, 40% on the east and west sides, whereas there are obviously no photovoltaic cells on the north side, for a total of 1,000 $m^2$ of active surface.
But photovoltaic cells are also present in the roof: the last level, consisting of the reception and meeting rooms, has a denser succession of photovoltaic cells on the glass roof. In the adjacent terrace, there are eight light wells that, thanks to the outside floor with photovoltaic cell inserts, guarantee light transmission and solar protection.
Once the entire construction is in operation, annual production should be around 80,000 kWh per year.

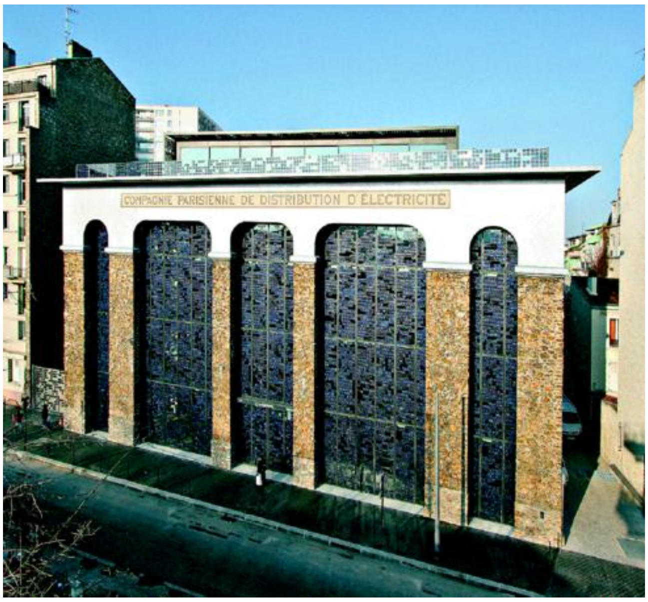


Fig. 6 - Le Losserand - Hôtel industriel, Paris

Fig.7 - Photovoltaic cells in polycrystalline silicon placed between the glass sheets

## Assessment sheet

| Building in Rue Le Losserand, Paris (F) – Photovoltaic system on façade glass windows | | | | | | |
|---|---|---|---|---|---|---|
| **Scale** | **Typological element** | | **Integration levels** | | | |
| | | | **Technological** | **Landscape** | | |
| | | | | **Formal** | **Morphological** | **Chromatic** |
| Microscale architecture Building-place-construction | Roof | Opaque surfaces | | | | |
| | | Transparent surfaces | | | | |
| | Façade | Opaque surfaces | | | | |
| | | Transparent surfaces | ● | ● | ● | ○ |
| | Plants | | | | | |
| Mesoscale Square-block-surrounding | Roof | | | | | |
| | Façade | | | ● | ● | ● |
| | Plants | | | | | |
| Macroscale territory | Roof | | | | | |
| | Façade | | | ● | ● | ● |
| | Plants | | | | | |

Integration level: ○ = partial; ● = total

| Building of Rue Le Losserand, Paris (F) - Photovoltaic system on the façade windows | | | | | | |
|---|---|---|---|---|---|---|
| **Scale** | **Typological element** | | **Integration levels** | | | |
| | | | **Technological** | **Landscape** | | |
| | | | | **Formal** | **Morphological** | **Chromatic** |
| Microscale architecture Building-place-construction | Roof | Opaque surfaces | | | | |
| | | Transparent surfaces | ● | ● | ● | ○ |
| | Façade | Opaque surfaces | | | | |
| | | Transparent surfaces | | | | |
| | Plants | | | | | |
| Mesoscale Square-block-surrounding | Roof | | | | | |
| | Façade | | | ● | ● | ● |
| | Plants | | | | | |
| Macroscale territory | Roof | | | | | |
| | Façade | | | ● | ● | ● |
| | Plants | | | | | |
| Integration level: ○ = partial; ● = total | | | | | | |

## 11. Conclusions

The energy redevelopment of a historic building is a delicate matter, which has to consider not only engineering aspects related to energy saving and use or renewable energy sources, but also historic and architectural constraints and the conservation requirements of the artefact. From this perspective, neither traditional energy audit nor solutions based on design criteria adopted for other buildings (according to regulations and standards under force) should be considered. Each building has to be treated as a "unique case" requiring a close cooperation with the authorities of conservation. Herewith an integrated approach, which allows the identification of the most "convenient" energy improvement solution, while complying with conservation and integration cultural landscape requirements, has been shown. Such approach is detailed in the new REHVA Guidebook on "Energy efficiency in historic buildings" (REHVA, 2017), together with a collection of application example, which demonstrates how it is possible to achieve non-renewable energy saving while respecting the cultural heritage value of a historic building.

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